

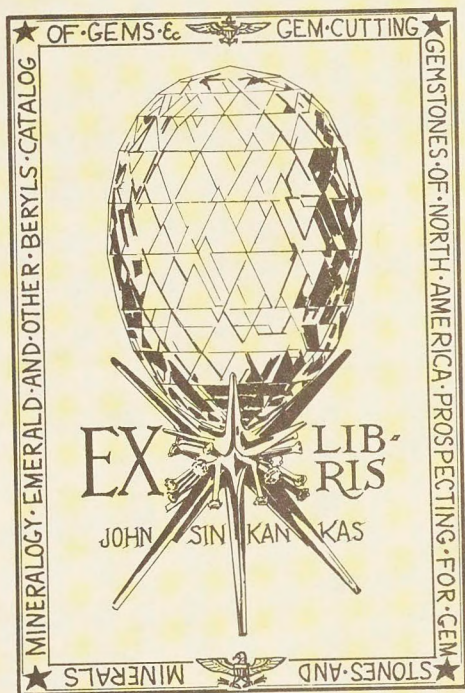
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With compliments from the Author.

Serpentine
(Switz.) Rauen-thal
—||—
Raisin





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ON THE NATURE AND ORIGIN OF
THE RAUENTHAL SERPENTINE.

On the NATURE and ORIGIN of the RAUENTHAL SERPENTINE.

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[PLATES XVI. & XVII.]

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INTRODUCTION.

THE general origin of the rock serpentine as a metamorphosed peridotite is now usually admitted since the investigations, which have become classic, of Profs. Tschermak, Sandberger, Bonney, and other later observers. An exception is made, however, for certain masses by some geologists. One of the most interesting of these is that described as the Rauenthal serpentine. The hypothesis which was put forward by Weigand in 1875¹ was that this did not originate from a peridotite, that it is indeed a metamorphosed rock, but is the result of the metamorphosis of part of a gneiss. The investigation of the genesis of this rock thus has a bearing on an important general petrological question. Exception was taken to the conclusions of Herr Weigand by Prof. Bonney from the study of microscopic slices.² In consequence of this, on my return journey from Switzerland in 1895, I turned aside to visit the Rauenthal, and brought back a few specimens, with the idea that they might be useful in the further examination of the question which I hoped that Prof. Bonney intended to make. As, however, it was not possible for him to visit the locality himself for some time, he asked me to continue the investigation, which I did in the summer of 1896, spending about a fortnight in the district. From the numerous specimens then collected, many slides have been prepared, the inferences from which seem entirely to corroborate the views formed on the spot. I have been able fortunately to submit to Prof. Bonney the specimens and slides, and he kindly allows me to state that he agrees with the main conclusions from them as here put forward. For all the help of various kinds given to me by him in this investigation, and for the facilities most generously afforded for examining his numerous specimens of serpentines from other localities, I would here offer my best thanks.

¹ Jahrb. d. k.-k. Geol. Reichsanstalt, vol. xxv. (1875) p. 183; or Tschermak, Min. & Petr. Mitth. 1875.

² Geol. Mag. 1887, p. 65.

I. INVESTIGATION IN THE FIELD.

The outcrop of the Rauenthal serpentine is marked on the French map published in 1837¹ as a somewhat lenticular patch rather more than 1200 metres from S.W. to N.E. by 200 metres from N.W. to S.E., occurring between 'granulitic gneiss' below and 'granulite' above. A small tributary streamlet² seemed to be fed by springs near the upper limit of the serpentine, to fall over a steep rocky bed westward in a course roughly determined by the northern boundary of the outcrop, although cutting through one corner, then to continue to the north and north-west into the Rauenthal stream. The steep hillside is often covered with grass or a close growth of ferns or flowers, and much of it is richly wooded. Fortunately several paths, and, still better, the road leading beyond the Schaafhaus, give easy access to the area which had to be examined.

(1) Relation of the Gneiss.

In the description given by Herr Weigand he speaks of a passage from the gneiss into serpentine. Therefore I first examined, as far as possible, the adjacent parts of the former rock. From the side of the path near the lower course of the above-mentioned streamlet, and from a quarry close by, I took several specimens, one being a well-marked hornblendic band, but the outcrop here by the path is small, and distant $\frac{1}{4}$ mile, or perhaps more, from the serpentine.³ The gneiss is well exhibited on the north of the stream along the road (marked a, Pl. XVI.) cut by it in small cliffs at intervals. This rock is foliated and banded; it sometimes has layers resembling a reddish granitoid rock, and others a foliated diorite; it is usually micaceous, and often has bands especially rich in biotite. The general dip here and in other masses is to the west of N. or to N.W., often at a considerable angle (45° to 60°). The gneiss, of perfectly normal type, is seen in a large mass at about 240 feet⁴ north of the stream, and in a small mass, apparently *in situ*, about 40 feet north of the stream, or 120 feet north of the serpentine. The actual junction south of the stream is obscured, but a sloping cliff of muddy talus extending about 80 feet seems to be full of fragments, some of slickensided schistose rock, such as often results from disturbance along a junction. Serpentine forms next a mass of tumbled big blocks, and then occurs as fragments in the earthy bank for about 470 feet. Beyond this the gneiss apparently extends

¹ Published by the Dépôt de la Guerre: scale $\frac{1}{80,000}$. This map is rather later in date than that of Köchlin-Schlumberger to which Weigand refers.

² Marked with more accuracy on the German contour-map of the district, not coloured geologically (scale $\frac{1}{25,000}$). This is the streamlet along which scattered blocks can be traced, as described by Weigand.

³ At this distance, or farther from the serpentine, some of the rock is a hornblende-schist or foliated diorite.

⁴ All measurements are very rough calculations, made from pacing the distances.

until we reach the granite rather north of the next tributary streamlet.

Here, then, was the first result which I had not anticipated. No clean continuous sections were found, showing a passage from gneiss to serpentine, nor even from gneiss to an almost pure amphibolite, and the gneiss seemed to be everywhere of normal type. Herr Weigand states in regard to this rock that the hornblende 'gradually gains the upper hand, and thus the rock passes through amphibole-gneiss to a pure hornblende-rock, which, however, retains the stratified aspect of the gneiss.'¹ Whatever changes have occurred in the local exposures (and it would have been perhaps a help if Herr Weigand had given a more detailed description of the parts which he examined in the field), it is difficult to see where the sections can have been which showed the passage stated.² As just previously recorded, in the gneiss almost adjacent to the serpentine (along the strike of the foliation) hornblende can hardly be found, all the dark layers which have been cut for the microscope proving to be micaceous; and although the mineral occurs in the valley below³ and in an occasional band on the lower slopes, this seems but slender proof of a gradual passage to an almost pure amphibolite.

(2) The Serpentine and its Relation to the Amphibolite.

The crags on the grassy and tree-covered slope consist mainly of serpentine *in situ*, and these were next examined.⁴ They generally face steeply towards the west or valley-side, and are often large masses extending 40 or 80 or even 150 feet in length, and to a height of 20 feet or more. Among them examples are soon noticed of the amphibolite and of various minerals associated with the serpentine, such as may have been found in blocks by the brook and roadstones in the valley. The chief rock is serpentine, often including, as described by Herr Weigand, a peculiar chlorite. That mineral is definitely orientated, the rock is generally platy, and its appearance on transverse and parallel surfaces is in marked contrast. On the former it looks dull, of a rather varied dark green colour, with slightly marked lines along the edges of the planes rich in chlorite. If these are exposed in step-like fashion, or if the rock be broken parallel with them, the chlorite gives a silvery glitter to the

¹ 'Diese letztere [Hornblende] gewinnt nach und nach die Oberhand und führt so das Gestein durch Amphibolgneiss in reinen Hornblendefels über, der aber die Schichtung des Gneisses beibehält.' *Op. cit.* p. 197.

² The road has been made somewhat recently, I believe, and doubtless changes have occurred in the sections exposed. But along the smaller (and, I should think, older) path above (marked β) gneiss is seen, in small outcrops towards its southern end, and in bosses north of the stream, and these are of the same normal type.

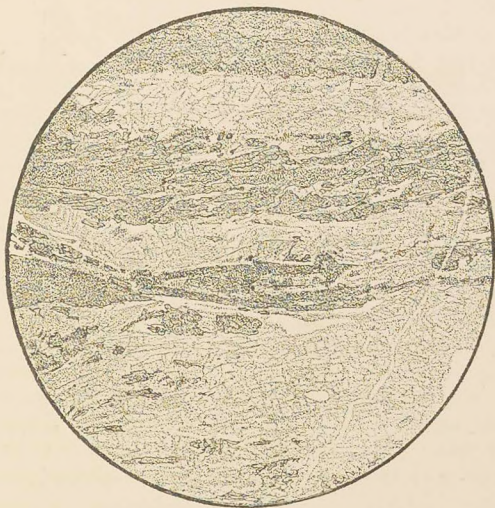
³ This would be rather distant, as previously stated, unless more crags occur which I failed to see, because they were hidden by the trees on the lower slopes of the hill, and even these would not be close at hand.

⁴ One or generally several specimens were taken from each mass. I believe that I examined every crag, but I certainly left no important section untouched.

surface. In the serpentine, enstatite-crystals are sometimes seen on the cross-fracture planes, where the chlorite is not visible. This platy serpentine rich in chlorite can be recognized in many crags (see Pl. XVI). In a second form of the rock the chlorite-flakes are much smaller, more crowded, and not orientated. A third variety is massive, dark rich greenish, not platy, without chlorite, but containing well-developed enstatite or bronzite. Fourthly, the serpentine may be mottled with greenish patches, or a similar material may form streaks and laminae sometimes about $\frac{1}{8}$ inch thick; these patches and layers are somewhat indefinite in outline.

Lastly, the peculiar amphibolite occurs in places. Where typically developed it is a beautiful mass of glittering, silvery, pale-greenish crystal-flakes, orientated so as to produce an appearance of foliation. Examples of it are found in at least five of the serpentine-crags. It often forms layers an inch or two in thickness embedded in normal serpentine, and the two rocks are clearly distinguishable in the crags, although the boundary is not always sharply defined, a certain indentation or mixing being visible on close examination.

Olivine-serpentine and 'amphibolite' (Rauenthal) in thin section.



The darker-spotted parts represent the distinctly green portions of the slice, which are composed of olivine-serpentine. The paler areas represent the 'amphibolite,' which is colourless. ($\times 2\frac{1}{2}$.)

Thus the amphibolite-bands occur not along the limit of the serpentine, but included in it (see Pl. XVI). Again, the loose blocks in the valley show the amphibolite and serpentine in similar relations. Another mode of association, however, is exhibited in certain loose boulders, and in one crag near to and south of the streamlet.

Here angular and irregular patches of serpentine and amphibolite are intermingled, giving the appearance of a breccia.

This occurrence of hornblende bands and patches presumably represents the passage of the amphibolite into the serpentine described by Weigand. In these separate bands or streaks, as also in the chlorite-bearing serpentine, a parallelism and orientation of the minerals is usually found, and Herr Weigand speaks of this as if only one cause could bring it about. He states that the serpentine 'lies in the amphibolite and in the strike of the gneiss; it is thus a metamorphosed banded complex of hornblende-rock.'¹ As will be seen from my description, the fact is rather that the amphibolite lies in the serpentine. A parallelism, however, with the foliation of the gneiss could be explained on the theory of the igneous nature of the serpentine and amphibolite. If a magma were intruded into a mass of gneiss, the intrusion would be likely to follow the structure-planes of that rock and to show a general parallelism with them.

(3) General Character of the Gneiss.

Finally, we must notice one general difficulty. The gneiss near the Rauenthal, as I have stated, is exposed, and exhibits a normal character over a large area. Occasionally (I should say rarely) it has bands rich in hornblende or composed of that mineral. In these, the hornblende, as Weigand describes it, is the dark greenish variety usually found in the gneiss. The rock shows the usual alternations of layers: quartz and felspar, biotite and felspar, or quartz, felspar and mica. Yet, on Weigand's hypothesis, the gneiss becomes in one isolated locality a mass of almost pure hornblende. Nowhere else in the neighbourhood is this representation found.² The only evidence for it here consists, first, in a comparatively few isolated layers of the peculiar pale amphibolite (and no hypothesis is put forward to explain the supposed bleaching and modification of the dark mineral of the gneiss), and secondly, in a mass of serpentine into which the hornblende-rock is supposed to be changed. Of the latter alteration we may at least say that it is neither usual nor easily explained. Even if there were a passage, of which I can see no evidence, this general difficulty should have been discussed.

On Herr Weigand's measurements, the serpentine-outcrop is 30 paces broad,³ and the occurrence of hornblende bands a few inches in thickness would not afford much material for so massive a development.

¹ 'Er liegt im Amphibolit und im Streichen des Gneisses; er ist also ein umgewandelter Schichtencomplex von Hornblendefels.' (*Op. cit.* p. 203.)

² As Prof. Bonney points out, a large mass of either pure hornblende or pure pyroxene is certainly very rare. (*Geol. Mag.* 1887, p. 66.)

³ 'Die grösste Breite des Serpentinanstehenden ist ungefähr 30 Schritte' (*op. cit.* p. 197). My own very rough measurements up the steep, covered, boulder-strewn slope gave the outcrop as about 260 yards broad. This agrees better with the map, but would increase the difficulty discussed above.

(4) Relation to the Granite.

I traced the serpentine upward, passing off it in many places until satisfied that I was on the granite and that no serpentine occurred higher up, since fallen blocks were not to be seen. The two rocks approach most closely along the upper course of the streamlet already noticed, especially below the road (δ) and above the little path (γ). Clambering here for a few paces at several spots over ground covered with soil and plants, I passed in each case from the serpentine to fragments and blocks, mostly moss-covered, consisting of granite, but I found no actual junction.

II. MICROSCOPIC DETAILS.

In the slides of rocks from the Rauenthal certain distinct minerals can be identified. For very many details about these we may briefly recapitulate the descriptions given in previous articles by Herr Weigand¹ and by Prof. Bonney.²

(1) Chlorite.

The shining folia visible macroscopically exhibit water-clear sections which extinguish straight, and are identified as chlorite often enclosing extruded iron oxide. In addition, they sometimes contain spindle-shaped crystals of another mineral*,³ probably aggregates of perovskite, or perhaps in some cases an impure sphene. The chlorite is associated either with the ordinary serpentine or with the amphibolite (Pl. XVII. figs. 4, 6). At places it shows in polarized light transverse bands like strain-shadows, so that it imitates the twinning of feldspar, and has almost a microcline appearance.⁴

(2) Hornblende.

Clearly-marked hornblende occurs within the serpentine, in longitudinal sections with rectilineal structure and in transverse sections with lattice-work, both often showing partial alteration, as described by the above-named authors⁵ (Pl. XVII. fig. 2). There would be no difference of opinion that such crystals are undergoing serpentinization, and that these serpentinized parts retain the characteristic indication of hornblende-cleavages. The transverse serpentinized bars may be somewhat sinuous and fringed, but the longitudinal planes extend as straight boundaries to the kernels of

¹ 'Die Serpentine der Vogesen,' Jahrb. d. k.-k. Geol. Reichsanstalt, vol. xxv. (1875) p. 197.

² 'Note on Specimens of the Rauenthal Serpentine,' Geol. Mag. 1887, pp. 65-70.

³ The * indicates a mineral not mentioned in Weigand's description.

⁴ I found in another slide a twinning somewhat resembling the above in a mineral which I believe to be pyroxenic, probably enstatite. Cf. T. G. Bonney, Geol. Mag. 1887, pp. 239, 240.

⁵ *Id. ibid.*; also J. J. H. Teall, 'British Petrography,' 1888, p. 111.

hornblende. Although the original hornblende-crystal has in the process of change become ragged and often irregularly replaced at the exterior by the mineral serpentine or actinolite, yet in a few cases a definite external form can be traced. An idiomorphic character would not have been generally acquired in the original crystallization of hornblende any more than in other hornblende peridotites or in the amphibolite of this area. The pale hornblende which forms the last-named rock consists of crystals often bounded by straight sides (generally prism-faces) and exhibiting perfect cleavages, but with ragged ends (Pl. XVII. figs. 4 & 5). Most of the mineral is fresh, but occasionally it is broken up into an aggregate partly serpentinous, partly actinolitic, which begins in tooth-like projections penetrating into the hornblende.

(3) Enstatite.*

This mineral can be identified by various characters. It exhibits close parallel structure, with straight extinction, appears streaked at least partially with serpentine, and includes, along the structure-planes, minute tubular enclosures, or some clustered brownish crystals, probably perofskite. The enstatite is undergoing serpentinization and is similar in its characters to that which Weigand describes as forming the major part of the Starkenbach mass, which, partly from this fact, he infers to have an origin different from that of the Rauenthal rock.

(4) Augite.*

Augite occurs in one slide, although it is in a layer of amphibolite, and thus, according to Weigand's hypothesis, not within an original peridotite. The augite is colourless, fresh-looking, with well-developed cleavages seen both in transverse and in longitudinal sections. The crystals are partly idiomorphic (with planes 110, 101, 011) and are enclosed within the hornblende.

(5) Iron Oxide.

Secondary minerals occur, one of the most important of which is iron oxide, commonly associated, as Weigand describes, with the chlorite, and often in the form of hæmatite. Other minute grains of iron oxide will be noticed shortly as occurring in the serpentine.

(6) Perofskite.*

In connexion with the serpentinized enstatite, small crystals occur (about .025 mm. or less in diameter), sometimes in definite cubes or octahedra, but usually clustered. The mineral is clear, colourless, with a high refraction and rough-looking surface, and it has whitish or silvery lustre by reflected light. It apparently is perofskite.

The mineral within the chlorite (as mentioned above) has very

similar characters. In the enstatite and in some of the hornblende, gummy-brown granular aggregates are clustered along the cleavage-planes, and perhaps cause a filmy appearance over intervening parts. This also is not unlike perovskite, possibly a second form of that mineral or a stage in its development, but it is in grains too minute to be tested. The serpentinized hornblende in one slide encloses small rhomboidal nets, which might be clusters of a similar mineral, but have rather the appearance of skeleton crystals.

(7) Rutile.*

In one slide of serpentine (from a loose specimen) many of the rounded kernels within the network exhibit acicular brownish crystals. They are long, but too slender to be examined in detail. Their colour and form suggest a dark impure rutile, and geniculate twins, although not common, occur. The needles are developed usually towards the border of the kernel and point in a more or less radial direction. The late Prof. Carvell Lewis, as will be seen from his forthcoming work on the Genesis and Matrix of the Diamond, identified rutile in serpentinized olivine.

(8) Serpentine.

The mineral serpentine in these slides shows varietal forms. It may consist of tubular or fibrous elements, sometimes parallel in bundles, sometimes in a matted mass. This serpentine is greenish, gives yellowish polarization-colours, and extinguishes parallel to the direction of the fibres, which thus are probably chrysotile. Secondly, the serpentine may show the lattice-work or the somewhat rectangular network surrounding angular kernels as described by Weigand and others.¹ Thirdly, it exhibits kernels of less regular form which, although they sometimes have rectilinear boundaries, are generally rather more rounded. Several differences between the last two cases are often recognizable. These are for the most part best seen with high powers in ordinary light by the use of a diaphragm. The parts with angular network are paler in colour; the net gives an effect of higher refractive power than the mesh, appearing like a green rim bordering a colourless area. With crossed nicols, the rim gives low colours and extinguishes nearly or quite parallel, while the enclosed parallelogram is faintly or not at all doubly refracting. The part with rounded grains is greener, the kernels are paler, more highly refracting and prominent than the intervening bands; where they have a greener tint we may sometimes be looking at a band cut parallel to its plane. In either case the nucleus has no effect on polarized light, but the borders give the usual low colours of serpentine.

Thus, as was pointed out by Prof. Bonney, there are two type-

¹ This form of serpentine results from the alteration of hornblende, transverse sections of that mineral showing a lattice-structure, and longitudinal sections exhibiting the prism-cleavages crossed roughly at right angles by less regular lines.

forms of the serpentine, differing in several characteristics. Whether the fibrous part is connected always with one or the other form is difficult to decide, but it seems certainly in some cases related to the more irregular part, since it can be traced originating either as patches or as a fringe beginning to extend into the kernels. A fourth form of serpentine with close parallel structure has been noticed as the result of change in enstatite.¹

Although these observations thus agree with many of the details given by Herr Weigand, yet some additions to his list are required, and the presence of enstatite especially has an important bearing, as it is distinctly a mineral associated with peridotites or allied rocks.²

III. CONTROVERSIAL QUESTIONS.

The characters must now be considered in which, according to Weigand, the Raunthal serpentine is unlike the other masses, and by reason of which, according to the same authority, a different origin must be attributed to it.

(1) Accessory Minerals.

It is stated that 'the accessory minerals so characteristic of olivine-serpentine here are wholly wanting.'³ It is true that picotite does not appear to be present, but it is absent from other serpentines, and other accessories characteristic of peridotites (perofskite, rutile, enstatite) are found here.

(2) Iron Oxide.

A second important distinction is stated to be that, 'for one thing, strings of iron are entirely wanting, and in consequence differently coloured zones.'³ The serpentine in many parts has a rather uniform greenish tint, contains only minute specks of ferrite scattered within the kernels, or aggregated in minutely granular strings along the

¹ A kind of spherulitic serpentine also occurs within certain veins which cross the amphibolite. In one of these, a very pale greenish or yellowish isotropic ground exhibits, with polarized light, scattered stars which consist of fibres, evidently serpentine or chrysotile. A vein in another slide shows, in polarized light, a diaper-like pattern with black crosses similar to that of spherulitic rhyolites. At other parts wedge-shaped crystallites grow in tufts from the sides of the vein. I noticed a slight development of a similar structure in a serpentine from the Lizard.

² The views of Herr Weigand as to the Raunthal serpentine are quoted by Mr. Teall ('Brit. Petrogr.' 1888, pp. 110-112). We find it stated, however, in another place, in connexion with Sandberger's results, that 'one or more of the minerals, chromite, picotite, pleonaste, chrome-diopside, enstatite, and pyrope, are found in the typical peridotites. The occurrence of any of these minerals in a serpentine is therefore strong evidence that it has been produced by the alteration of an olivine-rock.' (*Op. cit.* p. 108.)

³ B. Weigand, *op. cit.* p. 201:—'Ferner fehlen hier im Hornblendeserpentin gänzlich die für den Olivinserpentin so charakteristischen accessorischen Mineralien. . . . Einmal fehlen hier gänzlich Erzschnüre und damit verschieden gefärbte Zonen.'

intervening bands, as indicated by Prof. Bonney.¹ Thus, even apart from the chlorite, iron oxide is not entirely absent²; but it is true that the strongly marked black or brownish network of many serpentines is not here visible.

I fail to see, however, that this fact leads to any other inference than that the original olivine was not a ferriferous variety. It would seem that the original magma was one rather poor in iron, for the colourless hornblende probably owes its peculiarity to a want of the ferruginous constituent.³ Much of the iron oxide which is present in the serpentine seems to be associated with the peculiar chlorite. In certain specimens, however, the olivine-serpentine is more ferruginous, with grains of magnetite (?) and so much scattered minute opacite that it gives a bluish tinge to parts of the slide; but here no chlorite is exhibited.

(3) Microscopic Structure of the Serpentine.

(1) After the accurate description of the serpentinization of hornblende, Herr Weigand goes on to state that 'the same arrangement is found everywhere in the serpentine,'⁴ and that it 'follows without doubt that . . . a serpentine . . . in great masses . . . has originated from amphibolite.'⁵ It was shown by Prof. Bonney that the serpentine had not so universal and uniform a character, and that the major part of it can be distinguished from the serpentinized crystals of hornblende.⁶ We cannot ignore the differences which certainly exist, which Weigand himself to a certain extent recognizes from his words the 'larger rounded parts.'⁷ This phrase alone suggests two differences; others have now been added; and the true explanation seems to be that the part with 'larger rounded' kernels is the result of the serpentinization of an olivine-mass (Pl. XVII. figs. 2, 6). In fact the hornblende occurs as an accessory in an original peridotite, just as that mineral is found in parts of the Lizard serpentine.

(2) We are told that this Rauenthal serpentine does not exhibit the 'irregular network' which is characteristic of olivine-serpentines.⁸ Here there is a network—it is only therefore a question of

¹ Geol. Mag. 1887, p. 68.

² Indeed this appears to be acknowledged, although the statements do not seem perfectly clear:—'Die Analyse zeigt also in Uebereinstimmung mit der mikroskopischen Untersuchung eine grosse Menge Eisen.' (B. Weigand, *op. cit.* p. 200.)

³ The analysis of the amphibolite given by Weigand includes Fe_2O_3 4.649, FeO 2.107, but the analysis was obtained, we are told, from material which included some serpentine.

⁴ 'Zeigt sich dieselbe gitter- und fensterformige Structur über das ganze Gesichtsfeld verbreitet' (*op. cit.* p. 198); ' . . . man im Serpentine selbst mittelst des polarisirten Lichtes den Chrysotil in derselben Anordnung überall wiederfindet wie in der Hornblende . . . ' (*op. cit.* p. 200).

⁵ 'Geht unzweifelhaft hervor, dass . . . wir also hier einen in grossen Massen auftretenden Serpentin haben, der aus Amphibolit entstanden ist' (*op. cit.* pp. 200–201).

⁶ Geol. Mag. 1887, p. 68.

⁷ *Op. cit.* p. 197: 'grössere rundliche Partien.'

⁸ B. Weigand, *op. cit.* p. 201.

the regularity in its arrangement. If there be any difference in this respect from other serpentines, there is a far greater difference between it and the changed hornblende.¹ Moreover, in the olivine of various rocks there is a marked difference in the amount of internal structure which it exhibits. While in many crystals no cleavage and only irregular cracks are seen, in others straight parallel lines of cleavage are well developed. Perhaps no better examples of the latter character can be found than in certain eulysites.² If, however, we examine for comparison other serpentines, we find in many that bands equally straight form the network; and the structure of the strings in the Rauenthal rock was stated by Prof. Bonney to 'agree perfectly with those in a normal serpentine.'³

(3) In the mode of development of the chrysotile, Herr Weigand sees evidence of the hornblendic origin of the rock. The fibrous aggregates, however, in some of these slides have not a regular arrangement, but form a matted mass. Again in other rocks, parallel sets of fibres can be found beginning to develop from olivine. Thus the fibrous serpentine may in some cases have originated by alteration of hornblende, but there seems no evidence that this derivation is a necessity; on the contrary, a development from olivine can sometimes be traced.

(4) Specific Gravity and Hardness.

I have tested four specimens of the Rauenthal serpentine, and have found in them a specific gravity varying between 2.53 and 2.62. These results differ little from those given by the Bonhomme (an admitted olivine-serpentine),⁴ or by similar rock elsewhere.⁵ A specimen of the amphibolite (chosen to include as little foreign admixture as possible) gave a specific gravity of 2.828.

Herr Weigand further states that the serpentine of the Rauenthal is distinguished by its greater softness (*op. cit.* p. 197). I find that the degree of hardness in certain type-specimens is nearly 4.0, while that given by the 'olivine-serpentine' (Bonhomme) is only about 3.0.

¹ The serpentine-bands in the network of an olivine-serpentine seem broader than those along the cleavages in hornblende. Further, in those slides which are cut across the structure-planes of the rock, a fair proportion of the recognizable hornblende-crystals show the lattice-structure. But if there be any marked regularity in the serpentine, the parallelepipeds mentioned by Weigand are mostly rectangular.

² It becomes a question whether the mode of origin of such a rock may not be related to the more perfect cleavage of the mineral. If we could connect the cause of this structure with the flow of the original magma of the eulysite (a character which seems indicated in the rock), this might have an interesting significance in connexion with structures in the Rauenthal serpentine.

³ *Geol. Mag.* 1887, p. 68.

⁴ Herr Weigand gives 2.713 for the freshest rock and 2.609 for one more decomposed (*op. cit.* p. 189). I obtained, for 3 specimens, 2.671, 2.622, and 2.52 respectively; but the rock is so variable that differences are easily explained.

⁵ For Lizard serpentines, see *Quart. Journ. Geol. Soc.* vol. xlvii. (1891) p. 466. Sp. gr. from 2.545 to 2.77 for 8 specimens; one other had a sp. gr. of 2.85.

(5) Presence of Chlorite.

One striking characteristic, macroscopic and microscopic, in the serpentine is the presence of the 'silvery scales,' or the peculiar chlorite which is stated to be one of the essential points of distinction. It depends, however, on the explanation to be given of the formation of this chlorite whether it can be used as an argument for the origin of the rock from an amphibolite. It was not at first easy to come to a conclusion on this point, and the question is partly connected with the relation of the rocks in chemical composition.

In the supposed chemical change of a hornblende-rock to serpentine, Weigand points out that there would be a decrease of silica, a proportional increase of magnesia, and the loss of most of the lime and alumina. For the latter changes he offers two suggestions: the first, that these constituent substances induced the formation of the chlorite; the second, that possibly layers might occur of poorly aluminous hornblende.¹ Of the latter suggestion it is only necessary to say that it would be as easy to demand a belief in layers of completely non-aluminous olivine, which would grant the whole contention. The former suggestion seems necessary to Herr Weigand's hypothesis, and demands the acceptance of his view that the chlorite is a new formation. But all that can be established on this point is that the extrusion of iron oxide and the general affinities of the mineral suggest its being in a secondary or modified condition. The sharp contours, however, and the general parallelism of the flakes, to both of which facts Weigand refers as evidence,² are surely no arguments for his view. If the chlorite were developed in the alteration of hornblende to serpentine (using up the spare alumina and possibly lime),³ it would be likely to occur interlocking with the serpentine, of an irregular form, and with a less uniform arrangement, as is usually the case in secondary minerals. Further, we find the chlorite sharply limited at its junction with a hornblende-crystal, or completely embedded in an enstatite, as if it represented an original constituent of the rock; in other words, it seems to be the modification of a mineral with a definite form. Although I had considered in the field the question of its development, and even had tried to trace a connexion with more than one occurrence of a mica, I owe to Prof. Bonney the suggestion of what I believe to be the correct view, reconciling seemingly conflicting appearances—that the chlorite probably is the result of change of a mica akin to biotite; if so, the original rock must have been related to a mica-peridotite. If the mica, as is probable, was a somewhat ferruginous variety, then, where it is deficient, the presence of a more ferruginous olivine may be explained. If

¹ *Op. cit.* p. 202.

² *Ibid.*

³ Herr Weigand notices the difficulty of the lime, and makes the significant remark that if not found in true chlorite in such large proportions it is not unusual in the mica group (*op. cit.* p. 200).

the magma there was poor in the lime,¹ alumina, and alkali necessary to form mica, the iron may have been used up in the composition of the olivine.

If, however, anyone maintains that the evidence just given for an original mica is not conclusive, difficulties still remain in Weigand's hypothesis. First, patches of the chlorite occur in the Rauenthal rock in parts where no hornblende can be traced, or flakes are isolated within olivine-serpentine (Pl. XVII. fig. 3). Secondly, in rock from other localities there is serpentinized hornblende, but no indication of chlorite. Thirdly, the chlorite occurs in Rauenthal specimens embedded among completely fresh hornblende, and thus apparently not associated with its serpentinization. Fourthly, so far from the presence of the chlorite differentiating, as we are told, this serpentine from serpentines which have originated from olivine-rocks, the mineral in question is found in the latter, as Prof. Bonney has pointed out,² and as will be described shortly in several examples.

Finally, specimens were found from Bonhomme, and afterwards from the Rauenthal, in which a transition from mica to a pale chlorite could be traced; and, as will be shown later, the structure of the platy serpentine would agree with this origin of the chlorite.

(6) Chemical Changes.

If the chlorite be thus a modification of an original mica, the process for the formation of the serpentine from a hornblende-rock would be quite inexplicable. The alumina (and possibly other constituents of the supposed hornblende), if not used in the formation of the chlorite, would have, as Weigand suggests, no place. In addition to this, however, the difficulty in the supposed chemical changes of the disappearance of silica or accession of magnesia is not touched. Thus, if we assume the quantity of the most persistent substance, alumina, to be represented by unity, and take the amounts of the other components as ratios to that in the amphibolite and in the bulk serpentine³ respectively, we find how very different is the composition of the supposed original rock and of that into which it is stated to change. Thus

the silica would be 27.305 : 1 instead of 6.898 : 1 ;
the magnesia „ 26.623 : 1 „ 3.902 : 1.⁴

¹ Since it was shown that the chlorite contained lime, then the original mica should have been a variety which included that constituent. The amount of lime, however, in the bulk analysis is slightly greater than would be explained by the quantity in the chlorite. The presence of perovskite might partly account for this.

² Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 466.

³ That this serpentine represents a normal average specimen may be seen by combining the analyses of the chlorite and of dissolved serpentine on the estimate that the chlorite forms roughly about $\frac{1}{10}$ or $\frac{1}{8}$ of the bulk of the rock, when a composition is obtained very near that of the bulk analysis.

⁴ Or compare the calculation given by Prof. Bonney, Geol. Mag. 1887, p. 67, and note.

Although it may not be possible to show the fate of the surplus silica,¹ this does not offer much difficulty if only a small amount of hornblende has been really transformed. In all cases of serpentinitization such a change takes place, but is not evident microscopically; and in the case of sundry hemithrenes, where there is distinct evidence of serpentine having formed from malacolite, no visible silica can be detected.

We conclude then, in regard to the Rauenthal rock, that serpentinitization occurs of occasional hornblende-crystals, and of some enstatite, but that the greater part is to be attributed to the serpentinitization of an olivine-rock, and that the probable origin of the chlorite is a modification of a mica.

(7) Structural Characters.

The structural characteristics of the mass suggest some further explanations. With regard to the amphibolite, Herr Weigand has described its peculiar foliated appearance. If the hypothesis put forward by him could not be accepted, there yet seemed a possibility that the rock might represent parts of the adjacent gneiss in contact with an igneous mass and modified by it. Indeed, my first examination of the locality suggested the possibility that one rock might have been included and partially melted down by an intruding magma, as has been proved to be the case in parts of Cornwall²; but the idea was clearly negatived by further evidence in the field and afterwards by that obtained by the microscope.

The amphibolite of the Rauenthal (with a foliated appearance) forms actual streaks or layers (sometimes a few inches thick) within the serpentine. Under the microscope these are seen to consist chiefly of characteristic and unaltered hornblende. But at parts of the serpentine itself the thin dull-greenish streaks ($\frac{1}{8}$ inch thick) previously mentioned are composed of similar hornblende, which, however, is partially serpentitized. The chlorite-flakes usually form thin layers, which help to give a platy habit to the rock—one of its distinctive characteristics (Pl. XVII. fig. 6). All these structures, so far as my observations went, have a general parallelism.³

In the different layers, however, streaks of other composition occur; thus, in an amphibolite-band, we find strings of serpentine or occasional chlorite, sometimes in fair abundance (see fig. on p. 249 & Pl. XVII. fig. 4). And the various minerals are not confined to special layers. Chlorite occurs, as Weigand states, scattered without orientation; the serpentine sometimes has a patchy look, and is dark green mottled with pale green—owing to an irregular mixing of serpentitized hornblende. As already stated, enstatite can be

¹ Is it possible that the brownish, somewhat amorphous-looking substance, found at places, could be opaline in its nature?

² Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 471.

³ This seems to be in a direction roughly parallel with the boundary of the outcropping serpentine; but the observations on this point were taken in bad weather, and must be further tested for confirmation.

recognized in the serpentine, and augite occurs in one part of the amphibolite.

There seems only one possible explanation—since the hypothesis of a modified gneiss is not alone improbable from *a priori* reasons, but also is contradicted by field evidence and by microscopic structure—namely, that the serpentine has been derived from a peridotite, *i. e.* from an igneous rock. The interlamination of the amphibolite, its boundary ‘not sharply marked off’ (as was described by Weigand), the ill-defined hornblendic patches and streaks, all point to gradations from the peridotite to the amphibolite. Similar variability also is shown in the amount and arrangement of the chlorite, and in the distribution of enstatite. Thus the evidence suggests that the original magma was somewhat variable (as often is the case, especially in magmas of a basic character),¹ and that the rock formed from it was sometimes an olivine-enstatite rock (saxonite), sometimes a hornblende-peridotite, or a mica-peridotite, or even a hornblende.

The parallelism of the structures has, however, to be explained, and it may be due to the same cause which has developed in many igneous rocks and complexes a fluidal banding or orientation. The mica-flakes would then lie in the direction of the flow, causing a platiness, possibly afterwards further developed by contraction, and the hornblende-crystals would exhibit a similar orientation. The arrangement of the chlorite, and the related platy structure of the rock, would be very difficult to explain on Weigand’s hypothesis as to the origin of that mineral. It is impossible to appeal to pressure as a cause; the whole rock, as shown in both the serpentine and the amphibolite, evidently is generally unmodified by any such mechanical force.

At places, rather ill-defined large patches of serpentine and of amphibolite are found, as if a brecciation had occurred, and the distinction between the two rocks here and at other places is macroscopically so evident that it suggests the possibility of magmas somewhat different in age. The gradations and intermixing, however, make it probable that this distinction originated by differentiation of a single magma, but whether at a comparatively late epoch after the intrusion had commenced, or whether earlier, it does not seem possible to prove. Only at the greater depths, separation by specific gravity on Soret’s principle might have acted, causing the less dense part of the magma, which solidified as amphibolite, to separate from the heavier part; and the fragmental appearance just mentioned might then be due to a kind of flow-brecciation. This pseudo-breccia is found in one or two crags towards the north-western border of the serpentine massif. In this direction the amphibolite appears to be more developed, not because it is due to metamorphosis of the gneiss (since serpentinized hornblendic patches and streaks occur, almost to the

¹ Cf. J. W. Judd, *Quart. Journ. Geol. Soc.* vol. xli. (1885) pp. 358, 390, where a peridotite is shown to pass gradually into a pierite or other minor varieties, and even into gabbro or dolerite.

opposite border of the outcrop), but possibly because it formed here the lighter upper part of the mass, like a kind of scum.

Thus I believe that the structural and mineralogical characters of the Rauenthal serpentine can all be explained by the intrusion of an original peridotite-magma¹ somewhat variable in its composition, and that they do not require the hypothesis of an origin different from that which has been proved for most serpentines.

IV. COMPARISON WITH OTHER SERPENTINES FROM THE VOSGES.

In order to test more fully the views set forth above, I have made a study of other serpentines, both from the Vosges and from more distant localities. So far as concerns the former, before comparing them with the Rauenthal serpentine, we must add certain types of rock and certain mineral constituents to those described by Herr Weigand; and some corrections must be made in the proportions which he assigns to the constituents.

1. Thus there is far more variation in each mass than he has observed, and at the same time far more similarity between those which he has taken as different masses. The Starkenbach and Bonhomme serpentines are described as originating from separate magmas,² but parts of the two rocks are almost identical. The Starkenbach mass is stated to be a bronzite-serpentine having olivine sometimes up to as much as 25 per cent.³ While one of my specimens agrees fairly well with this description, the proportions estimated by rough calculation in the slices of three others seem to give—in two of them, about 80 per cent. and 90 per cent. of olivine respectively, in another about 50 per cent. of augite. The Bonhomme mass is described as an olivine-serpentine, and therefore distinct from that of Starkenbach. As we have just seen, parts of the latter, however, are formed mainly of olivine, and it is acknowledged that in the former variations exist. Weigand speaks of 'only a few small flakes of hornblende' being accessory⁴ (besides picotite, modified 'garnets,' noble serpentine, and iron oxide), but this hardly describes parts of the rock which include about 60 per cent. of augite and hornblende.

2. The most important point, however, is the distinct resemblance of the Starkenbach and the Bonhomme masses to the Rauenthal rock, since both these are admitted by Weigand to be derived from forms of peridotite,—the first from a bronzite, and the second from an olivine-rock.⁵

(i) Thus one slice from Starkenbach is from a rock completely serpentized, evidently formed from two minerals—enstatite and olivine. The enstatite has the appearance described by Weigand,⁶ but the major part of the slide consists of serpentine undoubtedly

¹ The absence of intrusive 'dykes or branching veins' seems to be in harmony with the 'usual habit of peridotites and serpentines.' See T. G. Bonney, *Quart. Journ. Geol. Soc.* vol. lii. (1896) p. 29.

² B. Weigand, *op. cit.* p. 196.

³ *Ibid.* p. 194.

⁴ *Ibid.* p. 191.

⁵ *Ibid.* pp. 191, 196.

⁶ *Ibid.* p. 193.

having the meshwork-structure of a mass developed from olivine, and, except in the presence of rather more magnetite than occurs in most but not in all of the Rauenthal rock, this has a similarity, we might say an identity, with the parts of that serpentine which may be claimed as showing an olivine structure. In many kernels of the original mineral a border occurs, of slender rutile-rods with a radial arrangement as I have described it above in a Rauenthal serpentine (p. 253). In another slice from Starkenbach we can trace all stages in the alteration. In the completely altered rock, strings of serpentine, often straight, not seldom form a rudely rectangular network or even occasionally cross at angles of nearly 120° . In other words, it has the characters of most of the Rauenthal serpentine, but here is associated with distinct remains of olivine. Serpentinized enstatite and picotite occur, as described; a colourless hornblende and a white augite are also present.

(ii) The strongest resemblance, however, can be found in parts of the mass which is claimed by Herr Weigand as an olivine-serpentine—that at Bonhomme. This rock shows much variation, includes sometimes the patches described as modified garnets,¹ sometimes picotite in exceptional abundance, sometimes serpentinized enstatite or clustered augite or hornblende. Most of the serpentine has been derived from olivine, but at parts well-cleaved crystals of hornblende more or less serpentinized occur, which, like the chlorite or the hornblende within the Rauenthal rock, are ‘grouped in layers’ or ‘scattered quite irregularly.’ One slice which consists mainly of olivine (some kernels still remaining unchanged), but includes several crystals of partially altered hornblende, seems to give a perfect representation of what parts of the Rauenthal rock should have been at an earlier stage (Pl. XVII. fig. 1).

This mass it was which first furnished evidence, conclusive in my opinion, of the origin of the peculiar chlorite already discussed. Glittering silvery flakes occur on certain specimens,² and microscopic investigation proved their identity with the chlorite; but in the same slide the mineral could be traced associated with, and evidently developed from, a variety of mica. This is pale brownish, with pleochroism from almost colourless to that tint, and resembles the form of phlogopite seen in the Kimberley peridotite.³ A specimen from among tumbled blocks, which are almost *in situ* by the road just south of the col, has mica occurring in larger flakes, also large enstatite-crystals, and a bright green apparently chloritic mineral. The specimen is practically identical with a rock from Portsoy.⁴

¹ B. Weigand, *op. cit.* p. 190. The interesting structure of these must be left for future investigation, since it has no direct bearing on the question here under consideration.

² The chlorite is noticed by Delesse, who states that it differs from the variety formed from garnet in the Zöblitz rock, being less rich in iron: *Annales des Mines*, ser. 4, vol. xviii. (1850) p. 327.

³ *Geol. Mag.* 1895, pp. 497, 498. This mica seems to undergo change to vaalite or to silvery spangles.

⁴ For the loan of this and other slides from Portsoy I am indebted to Prof. Bonney.

Thus the most noticeable peculiarity in the Rauenthal serpentine may be connected with conditions characteristic of other peridotites.

Lastly, in both the Starkenbach and Bonhomme masses, a banding is well exhibited, being apparently the effect of a flow-structure similar to that which has developed some characters of the Rauenthal rock.

V. COMPARISON WITH SERPENTINES FROM OTHER LOCALITIES.

Other serpentines afford a valuable means of comparison on many points, and I have to thank Prof. Bonney for the opportunity of studying the large collection of slides of this rock made by him during so many years of his work.¹

First, as to the accessory minerals: while in some of the Lizard rocks picotite is well developed, many of them do not contain it; and even in outcrops of the Vosges (as Herr Weigand shows) it is found at some parts, while absent at others of the same massif. It is thus by no means universal as a constituent. Further, the occurrence in the Rauenthal rock of perovskite and of rutile, similar in character to that in other serpentines, has now been shown.²

The iron oxide visible in the slides in most of the Rauenthal specimens is small in amount, and this fact is associated with the character of the serpentine next to be considered, but the chemical analyses prove that a fair quantity of iron oxide is present. Much of it is connected with the chlorite, although some occurs in minute form in the serpentine.

The meshwork-structure of serpentine, now so well known, is not always universal (even in the rocks of one area); although no doubt would be entertained as to their origin from peridotites. The valuable article of F. Becke on the Stubachthal has recently expressed this conclusion.³ In the Rauenthal rock, however, a serpentinous network can be recognized generally, and, although it is usually somewhat regular in form, a similar rectangular net was traceable in the great majority of the slices from the Lizard rocks. No argument seemed more impressive than this likeness in the essential structure⁴ shown throughout so large a collection of specimens,

¹ The collections of slides which I examined included 43 specimens from 18 localities at the Lizard; others from Portsoy, Zöblitz, the Rauenthal, the Harz, Aberdeenshire, and New Brunswick.

² It is interesting to recall the fact that the mica-peridotite dyke of Kentucky is described by J. S. Diller as composed 'essentially of biotite, serpentine, and perovskite,' with small amounts of secondary minerals: *Am. Journ. Sci. ser. 3*, vol. xliv. (1892) p. 287.

³ 'A distinct serpentine occurs which is derived from a typical olivine-rock, and in which nevertheless the meshwork-structure is completely wanting in the changed parts,' *Olivinfels & Antigorit-Serpentin*, *Min. & Petr. Mitth.* 1894, p. 271.

Of the three types of serpentine enumerated by Mr. Teall ('*Brit. Petrogr.*' 1888, p. 115) the study of the Rauenthal rock seems to take away one chief example of the second, and the work of Herr Becke to lead to an important subtraction from the third.

⁴ A likeness which was previously indicated by Prof. Bonney, *Geol. Mag.* 1887, p. 68.

since it may be presumed that no one would maintain a hornblende origin for the Lizard serpentine.¹

A colourless hornblende is characteristic of various masses of serpentine. At places (as, for example, Portsoy), a peculiar amphibolite occurs which shows an almost exact similarity in microscopic structure to that of the Rauenthal; and in rocks from Portsoy and the Lizard the appearance of hornblende undergoing serpentinization is exactly represented. The garnetiferous serpentine from Zöblitz also may be closely compared in the character of the serpentinized hornblende, except that in one slide I found that the amount is far greater than is usual in the Rauenthal serpentine; but in others the hornblende-serpentine formed the smaller part of the rock, and the account given by Lemberg² describes the serpentine as originating from an olivine-rock containing some hornblende and garnets or their chlorite-pseudomorphs. Thus, in the first two characteristics, it may be compared with that of the Rauenthal.

The characteristic chlorite is not peculiar to the Rauenthal serpentine, for it was identified by Prof. Bonney in slices from the Lizard. Even there it suggested a possible bleaching of biotite.³ On examining these slices, I at once recognized the mineral as similar to that in the Rauenthal mass. It is represented also at Portsoy.

Mica has generally been described, occurring in serpentines or peridotites, as akin to phlogopite, and this seems to be the nature of the mineral from which the chlorite originated in the Rauenthal rock. Thus an interesting comparison may be made with the few and rare mica-peridotites which have been described.⁴

The chemical composition of the Rauenthal and of other serpentines shows so great a resemblance that it would be difficult to suppose that they had originated by alteration of two totally different rocks. One of the Lizard serpentines most closely related seems to be that from near Cadgwith, of dark or black colour. The microscope-slide also shows marked similarity, and exhibits chlorite as well as some hornblende. It may be convenient to place side by side the analyses of the two rocks, and of two others, which are interesting for comparison:—

¹ Residual olivine has been described at several localities, such as Coverack, Carn Sparnack, south of Kennacka, and others on the western coast.

² Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvii. (1875) p. 531.

³ Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 473, 474. Cf. slices from near Cadgwith, Porthalla, and other places.

⁴ The clustered chlorite in some specimens apparently has a similarity to the occurrence of mica in the mica-peridotite from Kentucky described by J. S. Diller, where the mica 'occurs in round or oblong patches.' It is, however, more abundant than it would have been in the Rauenthal rock and 'forms the groundwork.' Within the scales is scattered some serpentine. 'The biotite is occasionally altered to chlorite,' Am. Journ. Sci. ser. 3, vol. xlv. (1892) p. 287. The similar dyke near Ithaca, N.Y., is described by J. F. Kemp as occurring with 'the characteristic reddish biotite of the peridotites,' Am. Journ. Sci. ser. 3, vol. xlii. (1891) p. 411. Cf. also a dyke in Central New York, *ibid.* vol. xliii. (1892) pp. 322-327, C. H. Smyth Jr.; and the De Witt dyke, *ibid.* vol. xlix. (1895) p. 458, N. H. Darton & J. F. Kemp.

- A: The Raumenthal serpentine; the bulk analysis given by Herr Weigand.¹
 B: The matrix of the dark serpentine from near Cadgwith.²
 C: Dark oil-green serpentine from Porthalla.³
 D: A mica-peridotite from Kentucky, described by J. S. Diller.⁴ In this the high percentage of lime and alumina, and the low proportion of magnesia, can be accounted for by the large quantity of mica present.

	A.	B.	C.	D.
SiO ₂	36.944	38.50	37.15	33.84
TiO ₂ .....	.....	.....	.....	3.78
Al ₂ O ₃	1.353	1.02	5.60	5.88
Cr ₂ O ₃ .....	.....	.....	.....	0.18
Fe ₂ O ₃	6.868	4.66	1.10	7.04
FeO	9.563	3.31	8.80	5.16
MnO .....	.....	.....	.....	0.16
NiO .....	.....	0.59	.....	0.10
CoO .....	.....	.....	.....	trace
CaO	1.393	1.97	0.10	9.46
BaO .....	.....	.....	.....	0.06
MgO	36.022	36.40	32.80	22.96
K ₂ O .....	.....	.....	} 0.29	2.04
Na ₂ O .....	.....	.....		0.33
H ₂ O	13.089	12.35	} 0.46	7.50
P ₂ O ₅ .....	.....	.....		0.89
Cl .....	.....	.....	.....	0.05
F .....	.....	.....	.....	?
CO ₂ .....	.....	.....	.....	0.43
FeS ₂ .....	.....	0.41	.....	.....
Insol. in HCl .....	.....	1.37	.....	.....
Total.....	.....	100.58	100.00	99.86
Specific gravities.....	.....	2.587	2.56	.....

The significance of the occurrence of bastite as a point of likeness is so obvious that it need only be mentioned.

The variation in many masses is an important means of correlation, since it is from this character, or rather from the overlooking of it, that some difficulties in interpretation have arisen.⁵

The structural characteristics afford a means of comparison with other serpentines. For instance, in the Lizard rocks, the occurrence of a structure both on the eastern and the western coast, which resembles a slight foliation, has been noticed, and occasionally there is also banding, especially at Porthalla.⁶

¹ *Op. cit.* p. 199.

² Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 466. Analysis v., by Mr. Hudleston.

³ *Ibid.*, analysis vii., by Mr. Collins.

⁴ Am. Journ. Sci. ser. 3, vol. xlv. (1892) p. 288.

⁵ The variability of Lizard serpentines is well shown by the tabular summary, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 467.

⁶ Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 470, 472, 474. See also note on lherzolite written in 1876, quoted on p. 475. A banded specimen which I brought from Bonhomme is practically identical with that from Porthalla which is represented in pl. xvi.

A similar structure (fluxional or banded) has been observed in other holocrystalline igneous rocks, as in the diorites of Guernsey (Quart. Journ. Geol. Soc.

Thus a serpentine such as may be found at the Lizard exhibits marked likenesses to that of the Rauenthal. The bastite is similar, the accessory hornblende, the chlorite (although more common in the Rauenthal), the general network of the serpentine, the variability in the composition, and the occasional banding at the Lizard. It may perhaps be said that in the Rauenthal rock the olivine is a less ferruginous variety, and the mica richer in iron more common. But, with such marked likenesses, how could a different origin for the two masses be at all probable?

VI. SUMMARY.

The views of Herr Weigand on the Rauenthal serpentine are briefly as follows:—

That a passage can be traced, from the dark hornblendic bands of the gneiss (by increase and modification of the hornblende) to the pale greenish amphibolite, and from the amphibolite (by a process of alteration) to the serpentine.

That the chemical changes in the latter process can be explained, if we assume that chlorite is formed mainly from certain constituents of the hornblende.

That by microscopic examination a hornblendic structure is shown throughout the serpentine.

Therefore, that the serpentine here is the result of change, not of an igneous peridotite, as in neighbouring localities, but of part of the gneissic series.

The evidence opposed to this conclusion may be shortly stated:—

(I) That in the field we can trace no passage from gneiss to the peculiar amphibolite.

That no consideration is given by Herr Weigand to the general difficulty which would be involved by a peculiar and local modification of the gneiss such as is to be found nowhere else in the neighbourhood.

(II) That the chemical changes of amphibolite to serpentine as exhibited in his analyses cannot be fully explained; and that the chlorite seems more probably derived from an original mica.

(III) That on microscopic examination the hornblendic structure in the serpentine is seen to be limited to certain isolated crystals or crystalline layers or patches of original hornblende, and that the greater part of the serpentine appears to be derived from olivine. That enstatite, a constituent of peridotites, occurs here. That some iron oxide, minute rutile, and perovskite are also present.

(IV) That apparent gradations in the rock are connected with the different arrangements of hornblende, chlorite and enstatite. That this variation (of which the amphibolite may form an extreme case)

vol. xlviii. 1892, p. 135) and the gabbros at the Lizard (*ibid.* vol. xlvii. 1891, pp. 484-490). Cf. 'Brit. Petrogr.' J. J. H. Teall, pl. xliii. fig. 2. See also Report on Rocks of St. Paul's Island, Renard, *Chall. Exped. Narrative*, vol. ii. App. B, fig. 2, pp. 7, 14.

seems to be due to differentiation of an original magma, in which fluxion-structures were developed.

(V) Neighbouring serpentines in the Vosges are found to exhibit closer likeness one to another, greater variation in each mass, and more marked resemblance to that of the Rauenthal (in mineralogical composition and structure) than are described by Herr Weigand. Thus it seems impossible to maintain that the Rauenthal serpentine is distinct in its origin from these adjacent masses. Yet they are claimed by him as derived from peridotites (olivine- or enstatite-rock).

(VI) By comparison with serpentines from many other localities beyond the Vosges, such a likeness is found that it does not seem possible to attribute a different origin to the Rauenthal mass. As Prof. Bonney has said, possibly 'the white hornblende is rather exceptionally abundant'¹ and '(as sometimes occurs elsewhere) a peculiar variety of chlorite is locally developed.'² Otherwise, the Rauenthal rock resembles in structure, in chemical composition, in mineral constitution, and even in the variations of its minerals, certain serpentines from Cornwall, Scotland, and the Continent.

Thus the serpentine of the Rauenthal would be but one of the varied forms in which that rock occurs in the neighbourhood of the Bressoir. It seems to have developed there from a not very pure or an ill-mixed magma, which was sometimes an olivine-rock (a dunite), sometimes either an olivine-enstatite rock (saxonite) or an augite-olivine or a hornblende-olivine, or, as I believe, a mica-peridotite. These variations may extend over fairly large areas or may be closely associated as thin, probably fluxional bands, within the same mass. As, then, I cannot admit the Rauenthal serpentine to be anything but an altered peridotite, I should not expect that serpentines in other gneissic regions³ were unusual in their origin.

EXPLANATION OF PLATES.

PLATE XVI. (MAP).

The serpentine-bosses are marked diagrammatically, but the patches give a rough idea of the relative size of the different crags. The boundary of the outcrop cannot be traced with exactness, but indications are given by fragments of rock and by the contour of the ground; thus the curving line at the south-west is drawn roughly along the direction where a rather sudden steepening in the slope seemed to imply a change of rock. The minerals (chlorite, enstatite, hornblende) are indicated in the serpentine at places on the plan, as examples of the variation in its composition; but no attempt has been made to show exhaustively where these minerals occur.

The blocks and fragments of rocks are intended only to show general position.

Paths and roads are mapped from examination of the area by the Author.

¹ Not without parallels for comparison: for example, Zöblitz, Portsoy.

² Geol. Mag. 1887, p. 69.

³ B. Weigand, *op. cit.* p. 203 'Es steht mit Sicherheit zu erwarten, dass Serpentine ähnlicher Entstehung sich in Gneissgebieten in Menge finden werden.'

PLATE XVII.

All the figures are $\times 20$. Figs. 2-6 are of Rauenthal serpentine.

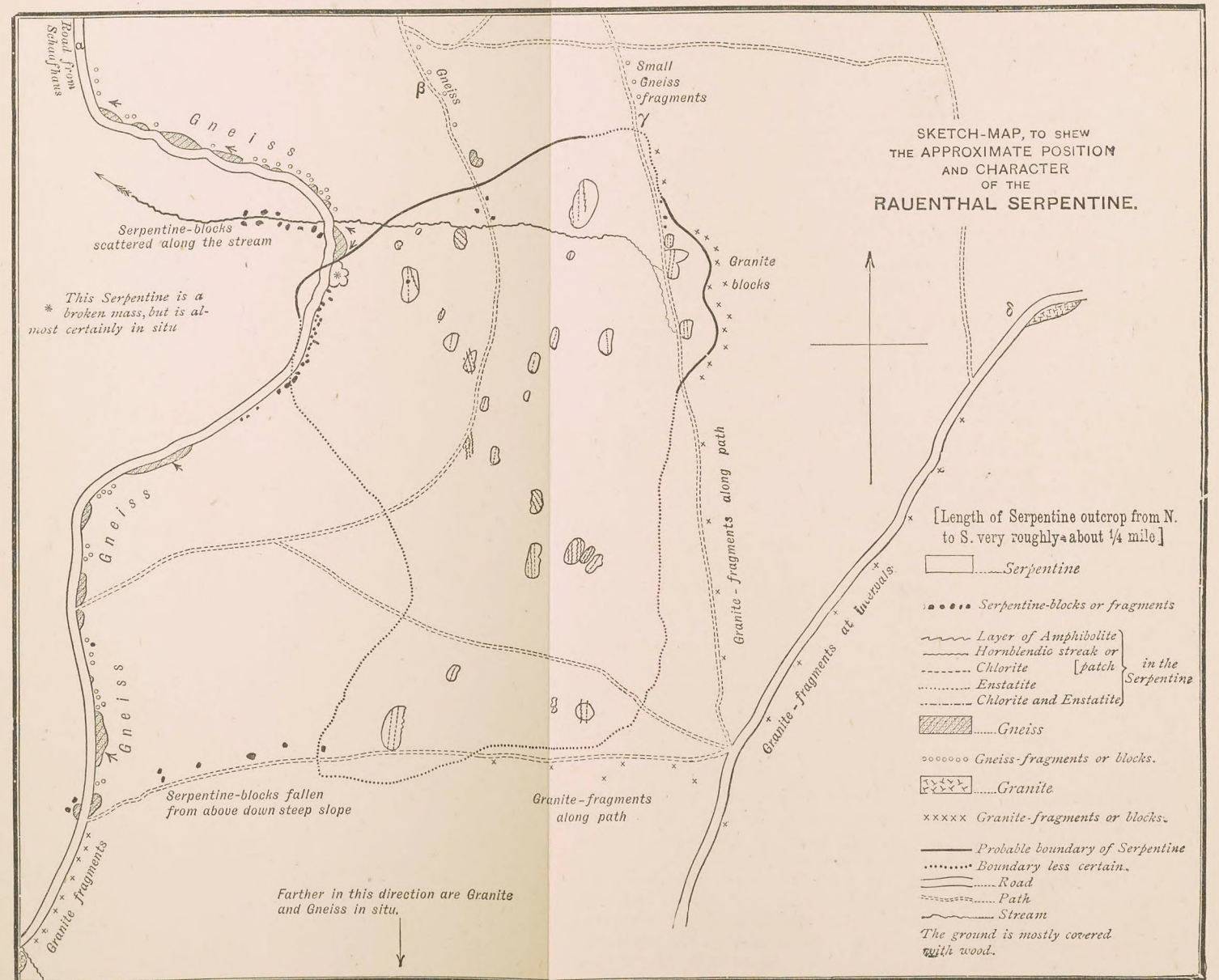
- Fig. 1. A slice from the Bonhomme serpentine (which is admitted to be an olivine-serpentine), to illustrate the similarity to the Rauenthal rock. The drawing shows accessory hornblende-crystals, serpentinized, among olivine-serpentine as in fig. 2 from the Rauenthal. The chief differences are, in the Bonhomme rock, the presence of picotite (represented together with opacite by dark spots in the drawing) and the occurrence of some residual unchanged olivine.
- Fig. 2. Crystals of accessory hornblende, serpentinized, but still exhibiting characteristic cleavage, within a mass of olivine-serpentine. Iron oxide, with amount and arrangement as usual, occurs in the slide. Serpentinized enstatite and chlorite are also present, but are not shown in the drawing. (The darker tint of this figure, as compared with fig. 1, is due to the slice of the rock being much thicker.)
- Fig. 3. Chlorite accompanying and enclosed within olivine-serpentine, associated with partly-changed hornblende. Some of the chlorite is in a transitional condition, evidently forming from mica. Crystalline grains of iron oxide are present.
- Fig. 4. 'Amphibolite' consisting of hornblende, mostly unaltered, sometimes in idiomorphic crystals, associated with well-developed chlorite. (Band in Rauenthal serpentine.)
- Fig. 5. Interstreaking of greenish olivine-serpentine and colourless well-cleaved hornblende ('amphibolite'). Iron oxide is present. Structure probably fluxional.
- Fig. 6. Olivine-serpentine, with the usual meshwork structure. Many of the fine dots over the grains represent minute granules of ferrite, probably hæmatite; and a few larger patches of opacite and ferrite are shown in the drawing. Chlorite occurs in parallel or orientated flakes, but no hornblende is associated with it.

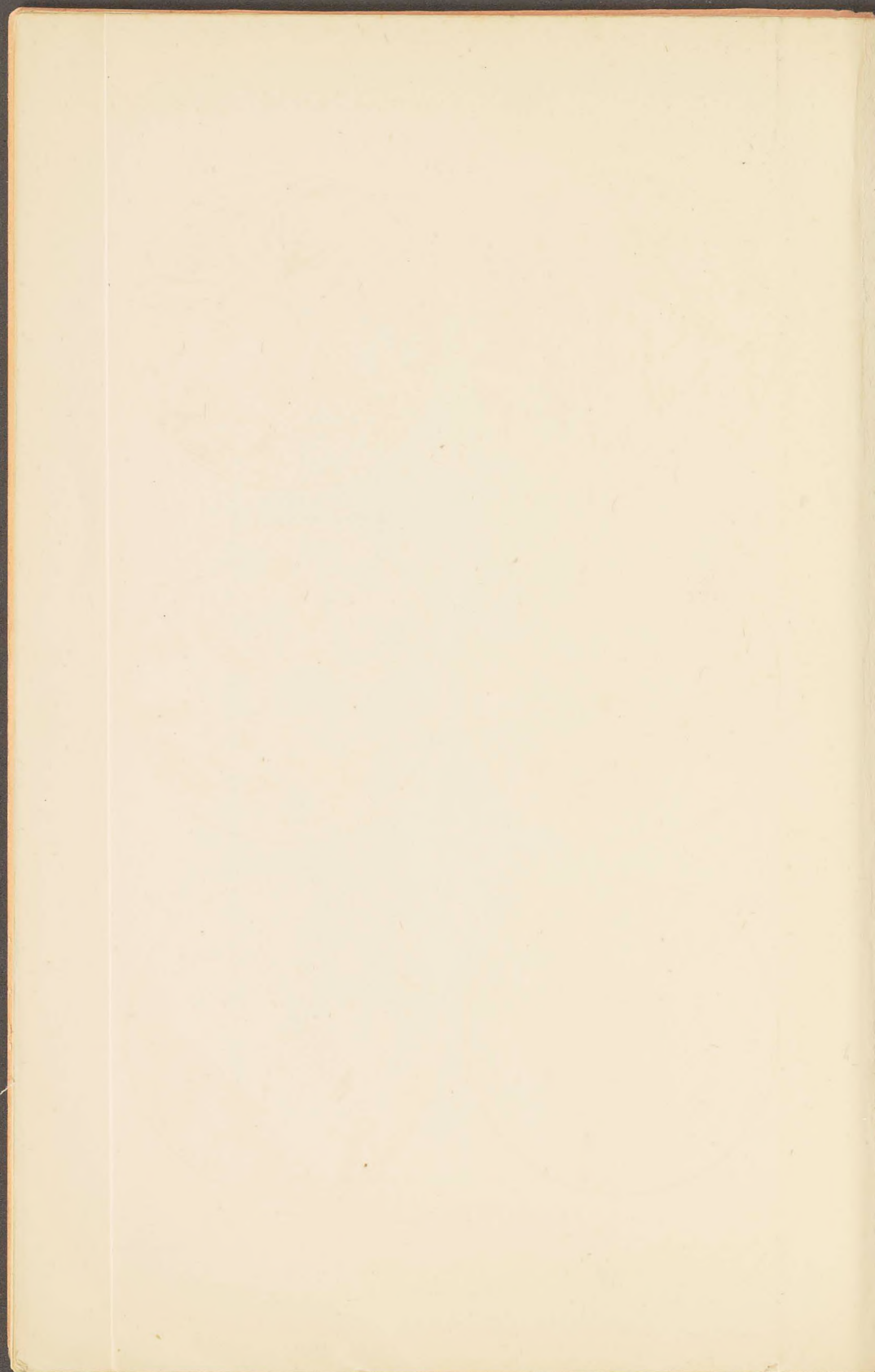
DISCUSSION.

Prof. JUDD called attention to the fact that the relations of the serpentine of the Rauenthal to the adjacent granites and gneisses, as described by the Author of the paper, are strikingly like those of the peridotites and serpentines of North Carolina and Georgia to the granites and gneisses of that area.

Mr. RUTLEY said that the rocks included within the area described would unquestionably yield serpentines varying considerably in character. One of these rocks was stated to be amphibolite, and, although the nature of rocks bearing this name is open to question, he thought that in certain cases amphibolites were eruptive rocks. When the hornblende of an amphibolite was converted into serpentine, it would be interesting to know what became of the other constituents. He appreciated the straightforward way in which only actual exposures were represented on the map, and believed that the paper, when printed in full, would be a valuable addition to the literature relating to serpentines and their origin.

Prof. BONNEY stated that the mode in which the serpentine occurred corresponded with what could be seen in several localities. The question of the connexion of the foliation of the serpentine with pressure had always been present to the mind of the Authoress, but no connexion had been proved. He agreed with Mr. Rutley that amphibolite was generally an igneous rock. There was a difficulty in accounting for the missing silica; but the fact of the change of certain pyroxenes into serpentine was indubitable. This rock, however, had originated from a peridotite.





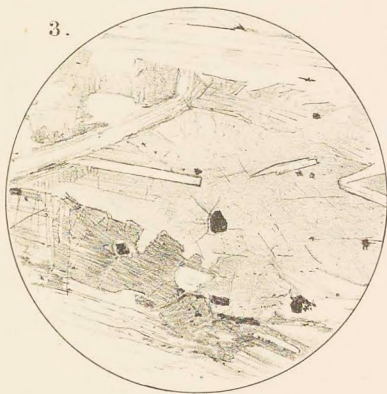
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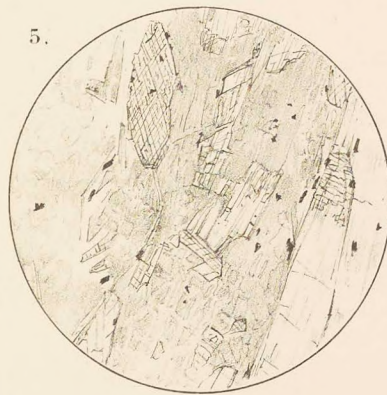
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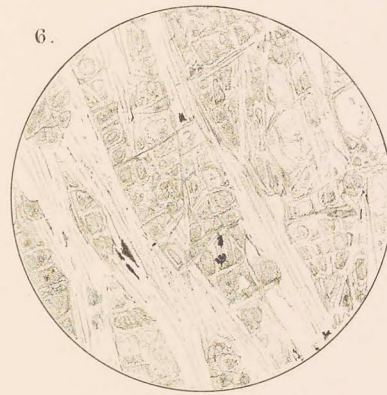
4.



5.



6.



F.H. Michael del. et lith.

Mintern Bros. imp.

THE RAUENTHAL SERPENTINE.

(Figs. 2-6.)

